

DECLARATION

I, Toshihiko Takano of c/o TAKANO & CO., 32-802, Kitamachi, Shinjuku-ku, Tokyo, JAPAN, hereby certify that I am the translator of the attached document and certify that the following is a true translation of the International Patent Application No. PCT/JP03/14784 (Specification, Claims, Abstract and Drawings) the best of my knowledge and belief.

Date: April 28, 2005

Signature:



Toshihiko Takano

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DESCRIPTIONPOLYSILOXANE HAVING PHOSPHORYLCHOLINE GROUP AND
PROCESS FOR PRODUCING THE SAME

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TECHNICAL FIELD

The present invention relates to a polysiloxane containing a phosphorylcholine group and a method for manufacturing it. The polysiloxane of the present invention is superior in biocompatibility and moisture retention, and is useful as a polymer material for medical use. Specifically, it is utilized in artificial organs, biomembranes, coating agents for medical tools, drug delivery, cosmetic ingredients, etc.

BACKGROUND ART

Polymers containing phosphorylcholine groups have been developed as biocompatible materials. Polymers having phosphorylcholine groups have been synthesized mainly as follows: acryl type monomers mainly having hydroxyl groups and 2-chloro-1,3,2-dioxaphosphorane-2-oxide are brought into reaction and then trimethylamine is used to turn the reaction product into quaternary ammonium to

synthesize monomers having a phosphorylcholine structure, which are then polymerized (refer to the following Patent Documents, for example).

Patent Document 1 describes the preparation
5 of a copolymer of 2-methacroyloxyethylphosphorylcholine and methacrylate, and Patent Document 2 describes the preparation of a homopolymer of 2-methacryloyloxyethyl phosphorylcholine.

10 Patent Document 3 discloses a cosmetic in which powder coated with a homopolymer or copolymer of 2-methacryloyloxyethyl phosphorylcholine is used as a cosmetic powder to improve moisture retention and adhesion on the
15 skin.

Patent Document 4 describes a polymer prepared by means of the graft polymerization of 2-methacryloyloxyethyl phosphorylcholine on water soluble cellulose; this polymer is utilized as a
20 polymer having blood compatibility.

Patent Document 1: Japanese Patent Laid-Open H9-3132 bulletin

Patent Document 2: Japanese Patent Laid-Open H10-298240 bulletin

25 Patent Document 3: Japanese Patent Laid-Open H7-

118123 bulletin

Patent Document 4: Japanese Patent Laid-Open H5-
345802 bulletin

A polyalkylsiloxane having phosphorylcholine
5 groups in its main chain has not been reported.

Due to the monomer solubility issues when
introducing the hydrophobic groups into the
polymer, the polymer preparation method in which
monomers having a phosphorylcholine group are
10 polymerized requires the use of an organic solvent
known as a chain transfer catalyst such as
methanol, ethanol, and chloroform as a
polymerization solvent, which makes it difficult
to produce high molecular weight polymers.

15 Also, there is a problem in that the steric
hindrance of the phosphorylcholine group reduces
the polymerization yield or makes it impossible to
obtain the desired polymer

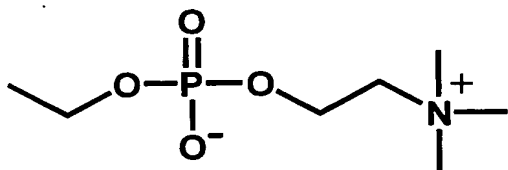
Also, the monomer synthesis reaction has to
20 be conducted under strictly anhydrous conditions,
which complicates the technique.

In view of the description above, the
inventors conducted earnest research to obtain a
polysiloxane that has a wide application range in
25 biocompatible materials and cosmetic ingredients,

and completed the present invention by discovering that a polysiloxane having a phosphorylcholine group can be obtained easily and with a high versatility by reacting a compound containing
5 phosphorylcholine groups with a polysiloxane having a functional group that reacts with this compound, which leads to a macromolecular reaction in the main chains or side chains of the polymer.

10 DISCLOSURE OF INVENTION

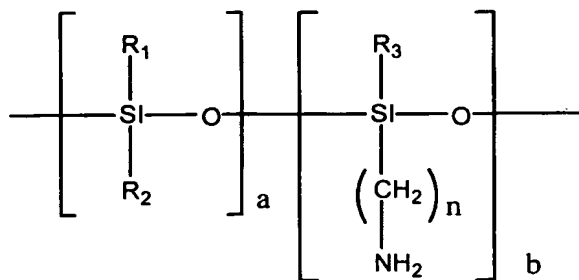
That is, the present invention provides a polysiloxane having a phosphorylcholine group represented by the following general formula (1).
(1)



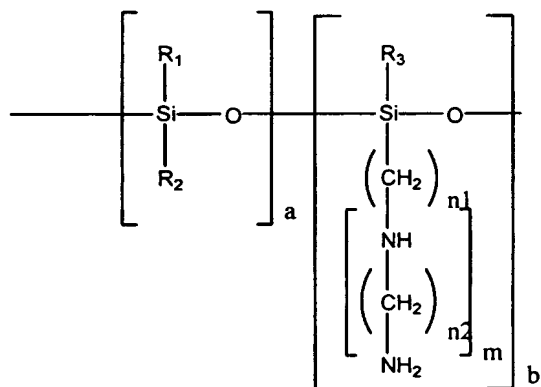
15 Also, the present invention provides a polysiloxane having repeating units represented by the following formulas (5), (6), and (7) obtained by introducing the phosphorylcholine group
20 represented by said formula (1) to some or all of the amino groups of amino-modified polysiloxane having repeating units a and b or repeating units a, b, and c represented by the following formulas

(2), (3), and (4).

(2)

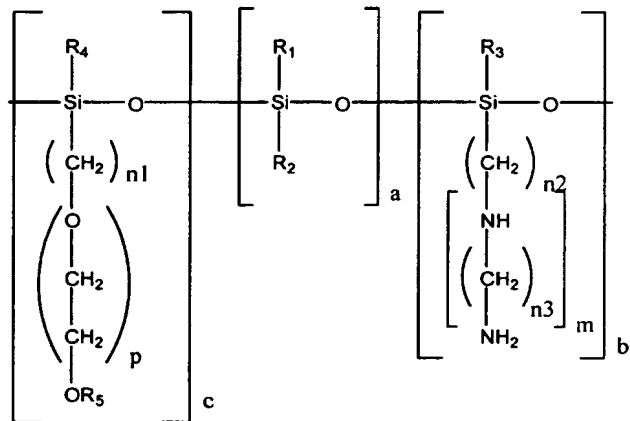


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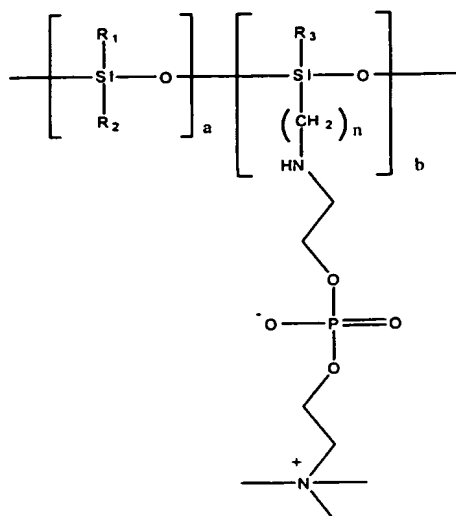


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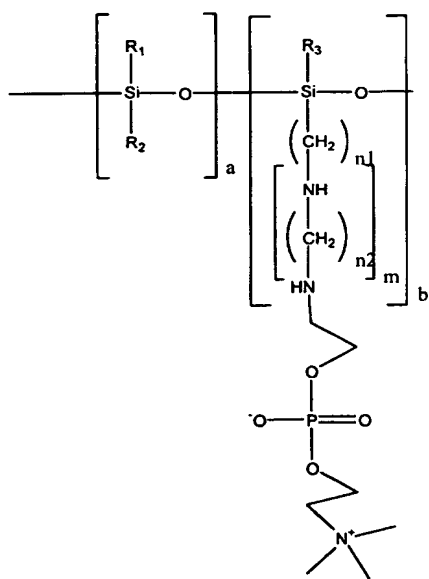
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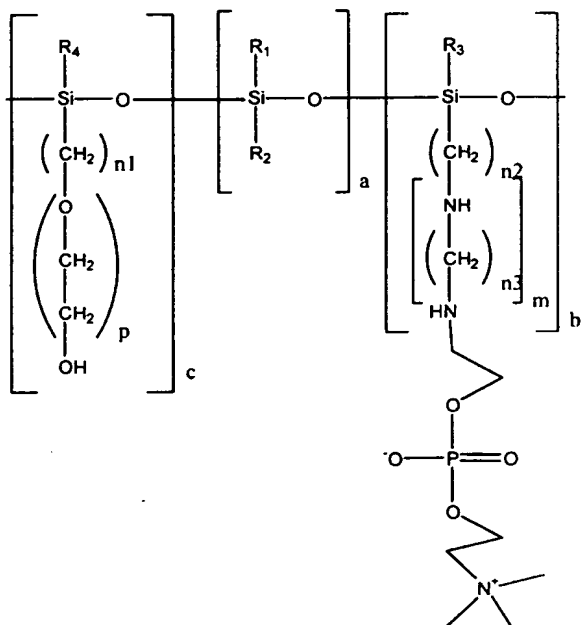
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(6)



(7)



R_1 , R_2 , R_3 , and R_4 , independently of each other, denote an alkyl group or perfluoroalkyl group having 1-22 carbon atoms, an alkoxysilyl group having 1-6 carbon atoms via an alkylene group having 1-6 carbon atoms, a phenyl group, or hydroxyl group; R_5 denotes a hydrogen atom or an alkyl group having 1-22 carbon atoms. n denotes an integer 1-22. n_1 , n_2 , and n_3 , independently of each other, denote an integer 1-22. m denotes an integer 0-10. p denotes an integer 1-30.

Furthermore, the present invention provides a method for manufacturing a polysiloxane having phosphorylcholine groups wherein the aldehyde derivative-containing compound obtained by the

oxidative ring-opening reaction of glycerophosphorylcholine is added to a polysiloxane containing amino groups.

5 BRIEF DESCRIPTION OF DRAWINGS

Fig. 1 shows a scheme for preparing a monofunctional aldehyde derivative having a phosphorylcholine group.

Fig. 2 shows a scheme for preparing a
10 polysiloxane containing a phosphorylcholine group by means of a macromolecular reaction.

Fig. 3 shows a structural formula and NMR spectrum of Synthesis example 1.

Fig. 4 is the polysiloxane of Example 1.

15 Fig. 5 is the polysiloxane of Example 2.

Fig. 6 is the polysiloxane of Example 3.

Fig. 7 shows a ^1H NMR chart of the polysiloxane obtained in Example 1.

Fig. 8 shows a ^1H NMR chart of the
20 polysiloxane obtained in Example 3.

BEST MODE FOR CARRYING OUT THE INVENTION

The present invention is described in detail below.

25 The polysiloxane having a phosphorylcholine

group of the present invention is prepared with the following method.

1: Amino groups are introduced to any
5 polysiloxane by using a prior art method or a method that will be developed in the future. Commercial amino-modified polysiloxane having primary amines or secondary amines may be used.

2: An aldehyde derivative or hydrate
10 derivative obtained by the oxidative ring-opening reaction of glycerophosphorylcholine is added to a polysiloxane having amino groups by means of a reductive amination reaction.

15 This preparation method has significant advantages in that the introduction yield is high and the introduction ratio can be controlled easily.

For example, the introduction ratio of the
20 phosphorylcholine can be controlled to freely adjust the hydrophilicity of the polymer according to the intended application. That is, the polymer design can be tailored to the required biocompatibility in the application of the
25 polysiloxane.

Also, free from the influence of the phosphorylcholine groups, the polysiloxane can acquire required functions by means of the introduction of hydrophobic groups and such, and
5 then any quantity of phosphorylcholine groups can be added to easily obtain the target functional polymer material.

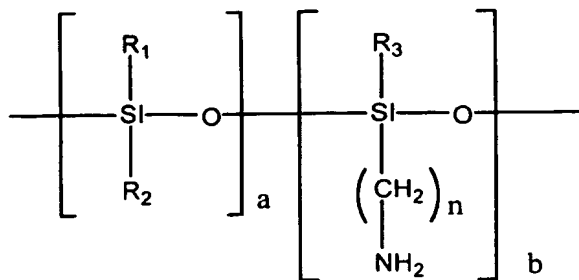
In the method of the present invention, the compound containing the aldehyde derivative
10 obtained by the oxidative ring-opening reaction of glycerophosphorylcholine is obtained by oxidative ring-opening of the prior art glycerophosphorylcholine group by means of a prior art method, which is a very easy step. This
15 reaction uses periodic acid or periodate to oxidize 1,2-diol to open the bond and obtain two aldehyde derivatives; in this particular method, a phosphorylcholine aldehyde derivative and formaldehyde are produced. The reaction is usually
20 carried out in water or in an organic solvent containing water. The reaction temperature is between 0°C to room temperature. The aldehyde derivative may go through an equilibrium reaction in water to become a hydrate, but this does not
25 affect the subsequent reaction with the amine.

Selection of the polysiloxane having amino groups is not limited in particular. It suffices if the side chains of the polysiloxane have amino groups with which the aldehyde derivative obtained
5 by the oxidative ring-opening reaction of glycerophosphorylcholine can react. The polysiloxane may have a substituent such as an alkyl group or phenyl group; such a substituent may have an amino group.

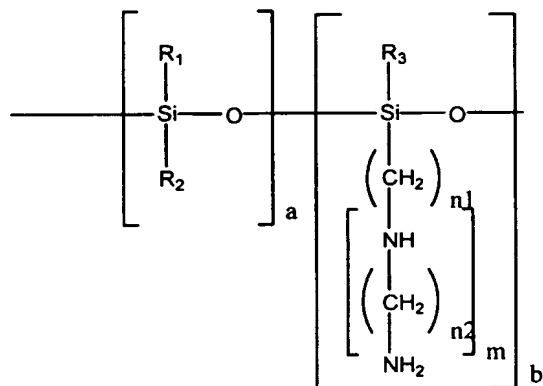
10 The amino group may either be primary or secondary. The amino group can be introduced to the polysiloxane by means of a prior art method or a method that will be developed in the future. Amino-modified polysiloxane, either prior art or
15 developed in the future can be used, too. There is no limitation in terms of the molecular weight of the amino-modified polysiloxane; polysiloxane of any molecular weight can be used.

Examples include an amino-modified
20 polysiloxane represented by the following general formula.

(2)

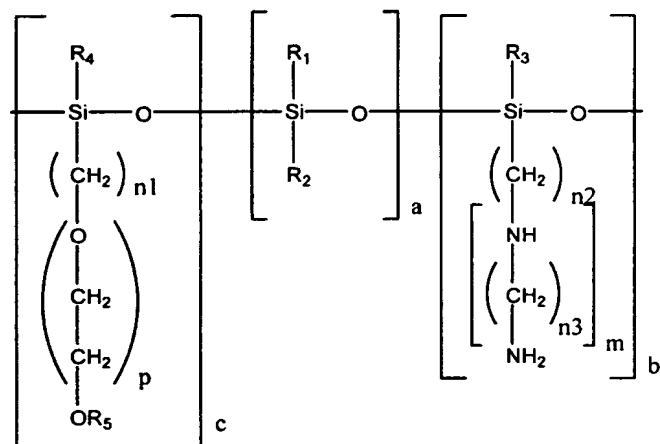


(3)



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(4)



In the formulas above, R_1 , R_2 , R_3 , and R_4 independently of each other, denote an alkyl group or perfluoroalkyl group having 1-22 carbon atoms, an alkoxysilyl group having 1-6 carbon atoms via

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an alkylene group having 1-6 carbon atoms, a phenyl group, or hydroxyl group; R_5 denotes a hydrogen atom or an alkyl group having 1-22 carbon atoms. n denotes an integer 1-22. n_1 , n_2 , and n_3 ,
5 independently of each other, denote an integer 1-22. m denotes an integer 0-10. p denotes an integer 1-30.

Also, a , b , and c denote constituent units of the polysiloxane, that is, the polymer has a
10 units, b units, and c units. Other constituent units may be contained in addition to polymers composed only of a units and b units and polymers composed only of a units, b units, and c units. Also, a units, b units, and c units may either be
15 arranged in a random fashion or in blocks.

When a , b , and c are represented by numbers, they denote molar ratios (polymer composition) of the corresponding constituent units.

The polysiloxane of the present invention is
20 a polysiloxane wherein the phosphorylcholine group represented by formula (1) is added to all or part of amino groups in the aforementioned formula. The ends of the polymer may be anything: for example, a hydroxyl group, alkyl group, hydrogen, and an
25 alkoxy group.

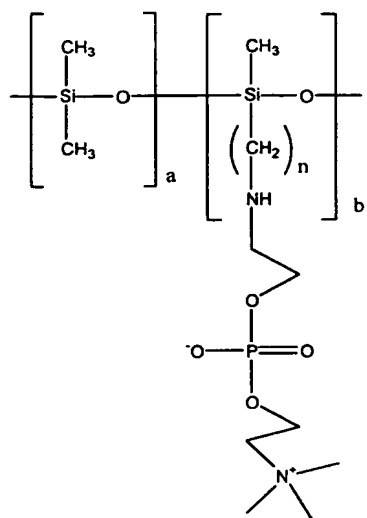
Preferable amino-modified polysiloxanes include a polysiloxane in which R_1 , R_2 , and R_3 are all methyl groups in formulas (2) and (3) and a polysiloxane in which R_1 , R_2 , R_3 , and R_4 are all
5 methyl groups and R_5 is hydrogen.

The preparation method of the present invention can use any amino-modified polysiloxane that is suitable for the intended application and allows easy preparation of a polysiloxane that has
10 the phosphorylcholine group represented by the aforementioned formula (1) added to all or part of its amino groups.

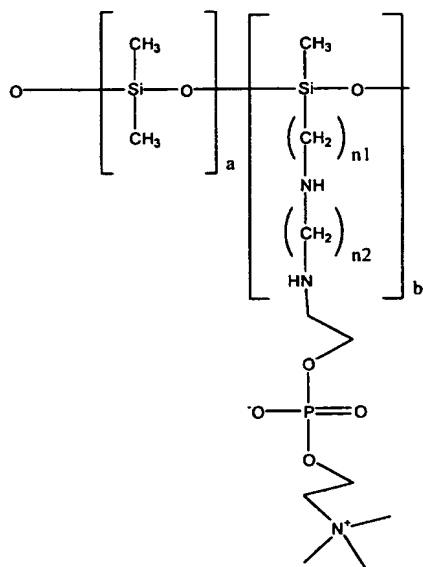
Specifically, a polysiloxane composed of constituents a and b represented by the following
15 formulas and a polysiloxane composed of constituents a, b, and c are preferably prepared. These polysiloxanes may contain a constituent b' that does not have a phosphorylcholine group added to its amino groups. That is, they are
20 polysiloxanes comprising an amino-modified polysiloxane that has a phosphorylcholine group added to some of its amino groups. The number of phosphorylcholine groups added to a polysiloxane can be easily adjusted by adjusting the mole
25 number of the aldehyde derivative containing a

phosphorylcholine group used for the reaction.

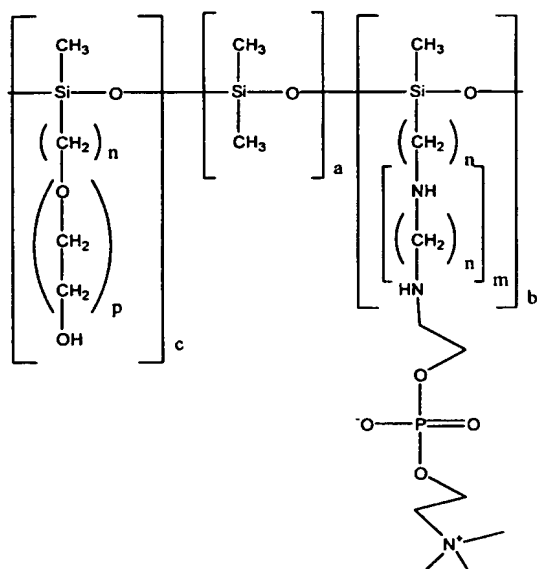
(8)



(9)



(10)



The reductive amination reaction for bonding the aldehyde derivative (or hydrate derivative) obtained by the oxidative ring-opening reaction of glycerophosphorylcholine to the amino groups of a polysiloxane can be carried out easily by stirring both of them in a solvent. This reaction is carried out by dissolving these two in water or alcohol (a third organic solvent ingredient can be mixed in, too) to form an imine and reducing it with a reducing agent to obtain a secondary amine. For the reducing agent, a mild reducing agent such as sodium cyanoboronate is preferable, but other reducing agents can be used as long as the phosphorylcholine is stable. The reaction is usually carried out at 0°C to room temperature,

but heating may be done depending on the situation.

Using the aforementioned preparation method, a polysiloxane containing a desired amount of phosphorylcholine groups in the hydrophilic portion is easily obtained. The molecular weight of the polysiloxane of the present invention can be any value. By using a polysiloxane having an optimum average molecular weight for the application, a polysiloxane containing a phosphorylcholine group having any molecular weight can be prepared. For example, a polysiloxane having a weight average molecular weight of 1,000-500,000 (standard polystyrene equivalent, measured with GPC) can be obtained.

Fig. 1 shows a scheme for preparing a monofunctional aldehyde derivative containing a phosphorylcholine group.

Fig. 2 shows a preparation scheme for the polysiloxane of the present invention.

For the hydrophilic portion of the polysiloxane of the present invention other than the polysiloxane group, a prior art method can be used to introduce, for example, a carboxylate group, hydroxyl group, primary-tertiary amine group, sulfonate group, phosphate group,

polyoxyethylene group, ammonium group, amide, carboxybetaine, and saccharide.

As for the hydrophobic portion, cyclic alkyls such as cholesterol, alkyl groups
5 containing unsaturated bonds such as oleyl, hydrocarbon type aromatics such as naphthalene rings and pyrene, hetero type aromatics such as pyridine rings, imidazole, thiazole, and indole can be introduced to create a design suitable for
10 the application. The hydrophobic group can bond directly to the main chain with the ester, ether, amide, urethane, or urea bond, or indirectly via a spacer. Examples of the spacer include hydrophilic polyethyleneoxide, hydrophobic polypropyleneoxide,
15 and straight chain alkyls having 2-22 carbon atoms.

The functionality of the polysiloxane can be freely designed by adjusting the type and content of the hydrophilic portion and the hydrophobic portion.

20 The polysiloxane of the present invention is superior in biocompatibility and moisture retention, and is useful as a polymer material for medical use. Specifically, it is useful in artificial organs, biomembranes, coating agents
25 for medical tools, drug delivery, cosmetic

ingredients, etc. It is particularly superior in the skin softening effect, moisture retaining effect, and the transdermal absorption of drugs in an endermic liniment.

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EXAMPLES

The present invention is described in detail below by referring to Examples. The present invention is not limited to the following Examples.

10 The composition of each constituent unit of the polysiloxane of the present invention can be determined by NMR. The blend ratios in the endermic liniment recipes for which the effect is verified are in mass percentage units of the total
15 amount.

Synthesis example 1 An aldehyde derivative containing a phosphorylcholine group

L- α -glycerophosphorylcholine (450 mg) is
20 dissolved in 15 ml of distilled water and cooled in an ice water bath. Sodium periodate (750mg) is added and two hours of stirring is carried out. Next, ethylene glycol (150 mg) is added and overnight stirring is carried out. The reaction
25 solution is vacuum-concentrated and vacuum-dried

and the target substance is extracted with methanol.

The structural formula and the NMR spectrum are shown in Fig. 3.

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Example 1 Synthesis of polyalkylsiloxane containing a phosphorylcholine group

1 g of amino-modified polydimethylsiloxane {commercial product KF-86 from Shin-Etsu Chemical Co., Ltd.: $R_1, R_2, R_3 = CH_3$, $n = 2-22$ in formula (2), average molecular weight 50,000} is dissolved in methanol (50 ml), to which 0.5 g of the aldehyde derivative in Synthesis example 1 is added, followed by 5 hours of stirring at room temperature. After cooling with ice, sodium cyanoborate hydride (250 mg) is added, followed by overnight stirring. The target substance (0.95 g) is obtained after purification by means of dialyzation and lyophilization. The obtained polysiloxane is shown in Fig. 4. For this, $a : b = 50 : 1$. A 1H NMR chart of the obtained polysiloxane is shown in Fig. 7. Solvent: Heavy water, standard peak: 1,4-dioxane, peak assignment: (1) 1,4-dioxane, (2) phosphorylcholine (quaternary ammonium), (3)

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siloxane (methyl). A peak (2) originated by the phosphorylcholine group appears.

Example 2 Polysiloxane containing a

5 phosphorylcholine

1 g of amino-modified polydimethylsiloxane {commercial product X-22-3939A from Shin-Etsu Chemical Co., Ltd.: $R_1, R_2, R_3, R_4 = CH_3$, R_5 is hydrogen, $n_1, n_2, n_3 = 2-22$ in formula (4),
10 average molecular weight 50,000} is dissolved in methanol (50 ml), to which 0.5 g of the aldehyde derivative in Synthesis example 1 is added, followed by 5 hours of stirring at room temperature. After cooling with ice, sodium
15 cyanoborate hydride (250 mg) is added, followed by overnight stirring. The target substance (0.9 g) is obtained after purification by means of dialyzation and lyophilization.

The obtained polysiloxane is shown in Fig. 5.
20 For this, $a : b : c$ is unknown.

Example 3 Polysiloxane containing a phosphorylcholine

1 g of amino-modified polydimethylsiloxane
25 {commercial product KF-393 from Shin-Etsu Chemical

Co., Ltd.: $R_1, R_2, R_3 = CH_3$, $n_1, n_2 = 2-22$ in formula (2), average molecular weight 3000} is dissolved in methanol (50 ml), to which 0.5 g of the aldehyde derivative in Synthesis example 1 is added, followed by 5 hours of stirring at room temperature. After cooling with ice, sodium cyanoborate hydride (250 mg) is added, followed by overnight stirring. The target substance (0.95 g) is obtained after purification by means of dialyzation and lyophilization.

The obtained polysiloxane is shown in Fig. 6. For this, $a : b = 5 : 1$. A 1H NMR chart of the obtained polysiloxane is shown in Fig. 8. Solvent: Heavy water, standard peak: 1,4-dioxane, peak assignment: (1) 1,4-dioxane, (2) phosphorylcholine (quaternary ammonium), (3) siloxane (methyl). A peak (2) originated by the phosphorylcholine group appears.

(1) The moisture retaining effect and the skin softening effect

Moisture retaining essences containing the polymer of the aforementioned Examples are prepared and comparison is made in terms of the moisture retention duration and the skin softening

effect. The recipes and results are shown in Table 1.

The evaluation is based on average scores of sensory evaluation by 20 specialists using the following criteria.

<Moisture retention effect>

3 points: The moisture retention effect lasts 10 hours or more after the application.

2 points: The moisture retention effect lasts 4 hours or more and less than 10 hours after the application.

1 point: The moisture retention effect lasts 1 hour or more and less than 4 hours after the application.

0 point: The moisture retention effect lasts less than 1 hour.

<Skin softening effect>

3 points: The skin becomes very softer after 1 week of use.

2 points: The skin becomes somewhat softer after 1 week of use.

1 point: The skin condition does not change after 1 week of use.

0 point: The skin becomes harder after 1 week of use.

<Evaluation>

◎ : The average score is 2.5-3 points.

○ : The average score is 2 points or more and less than 2.5 points.

5 △ : The average score is 1 point or more and less than 2 points.

× : The average score is less than 1 point.

Table 1

	Comparative example 1	Comparative example 2	Comparative example 3	Example 1	Example 2
Sorbitol	8	8	8	8	8
1,3-butylene glycol	5	5	5	5	5
Ethanol	7	7	7	7	7
POE oleyl alcohol ether	1	1	1	1	1
Olive oil	0.2	0.2	0.2	0.2	0.2
Purified water	78.8	78.7	78.7	78.7	78.7
Skin softening ingredient	None	Elastin 0.1	Sodium hyaluronate 0.1	Example 1 0.1	Example 2 0.1
Skin softening effect	△	○	○	◎	◎
Moisture retention effect	×	△	○	◎	◎

10 The results shown in Table 1 above indicate that the polysiloxane of the present invention has a superior moisture retention effect and skin softening effect and functions as an ingredient for cosmetics.

(2) The transdermal absorption accelerating effect

The transdermal absorption accelerating effect for drugs in an endermic liniment is tested with the following method disclosed in Japanese Patent Laid-Open 2002-71682.

The test is carried out in the in vitro fashion. The skin of a miniature pig is used as the skin model.

Arbutin is used for the drug. A simple aqueous solution of arbutin (Comparative example 4) and a solution that is this solution with the polysiloxane of Example 1 or Example 2 added to it are applied to the skin of a miniature pig, followed by a 6 hour incubation at 37°C; the epidermis is subjected to solvent extraction and the drug contained in a unit weight is quantified by means of HPLC to obtain the transdermal absorption for comparison.

The results are shown in Table 2.

The transdermal drug absorption ratio in Table 2 stands for (Arbutin absorption in Example recipe/Arbutin absorption in Comparative example 4 recipe).

These results indicate that the solutions

containing Example 1 and Example 2 have accelerated transdermal absorption of arbutin and therefore the polysiloxane of the present invention has a superior transdermal absorption accelerating effect for drugs in an endermic liniment.

Table 2

	Comparative example 4	Example 1	Example 2
Example 1		0.5	
Example 2			0.5
Arbutin	6	6	6
Physiological saline	94	93.5	93.5
Transdermal drug absorption ratio (Absorption in Example recipe / Absorption in Comparative example 4 recipe)	1	1.6	1.75

INDUSTRIAL APPLICABILITY

10 The phosphorylcholine group-containing polysiloxane of the present invention has high biocompatibility and moisture retention and is a useful polymer material; it has a variety of applications such as artificial organs,
15 biomembranes, coating agents for medical tools, drug delivery, and as cosmetic ingredients.

 The manufacturing method of the present invention using a macromolecular reaction has a great advantage in that it allows flexible
20 designing of a polysiloxane ideal for

biocompatible polymer materials for specific applications.

Free from the influence of a phosphorylcholine group, the structure of the main chain polysiloxane can be freely designed to obtain a material best suitable for the application, and then any quantity of phosphorylcholine groups can be added to easily obtain the target functional polysiloxane material.

A polysiloxane containing a phosphorylcholine group is superior in the moisture retention, skin softening effect, and transdermal absorption of drugs and therefore it can be blended into an endermic liniment such as cosmetics to provide a superior endermic liniment.